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Charles Gonzalez

TEST EFFECTIVENESS TREND OBSERVATION

The Use of Ground Testing to Reduce Potential In-Flight Anomalies

CONCLUSION:

A more rigorous ground test program could preclude in-flight anomalies. Potentially, 49 percent of the anomalies reviewed could have been detected by appropriate ground environmental testing alone. Detailed review of the cause of the anomalies indicates that some modification of current tests may be needed to increase the test effectiveness (e.g., greater instrumentation sensitivity, lower background noise, and assemblies powered and functionally monitored during testing, etc.) The Voyager test program provides the general guidelines for a superior test program.

REFERENCES:

1. Trend Observation TO-0016, Adequacy of Pre-launch Testing Based on Early Flight Anomalies, July 6, 1993.
2. Trend Observation TO-0003, Environmental Test Effectiveness as Indicated by Voyager and Galileo Anomalies, January 24, 1992.
3. Trend Observation TO-0017, Correlation of Advances in Spacecraft Digital Technology with EMC Failure Rate, August 23, 1993.

DISCUSSION:

An earlier study (Ref. 1) concluded that additional pre-launch testing or operations could reduce early flight failures. The basis for this conclusion was the fact that the anomaly rate immediately following launch was similar to the anomaly rate immediately before launch and that after a relatively short time in-flight, the anomaly rate decreased significantly. The relatively low anomaly rate continued for the remainder of the mission. If additional environmental testing is the correct approach, then review of the past in-flight anomalies for the pro ects should reveal causes for the anomalies that could be detected by additional ground testing.

Depending on the nature of the in-flight anomaly, a ground test might have to be modified to be an effective screen. For example, A longer test duration, higher test levels, or more sensitive test instrumentation may be required to effectively screen the underlying defect.

For example, some anomalies have occurred late in the mission related to noise spikes in science data which can be correlated to spacecraft events. Electromagnetic Compatibility(EMC) test personnel have found that some of these anomalies could have been screened out by employing more sensitive electromagnetic interference (EMI) detection instrumentation and

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simultaneously reducing the EMI background ground noise. Thus, for these anomalies EMC ground test modified in this manner would have provided a better screen. Consequently, where it is required, current EMC tests have been modified to incorporate more sensitive instrumentation and improved technique to lower background noise.

Based on these observations, a review of the Mariner 71, Viking Orbiter, Galileo, and Voyager early anomaly data was undertaken to determine whether a ground test could effectively identify the defects prior to launch. The anomalies reviewed were limited to those occurring during the first 200 days after launch (Ref. 1)*. As the anomalies were reviewed, the use of various ground test were considered as a means for screening the underlying defect. The criteria for assigning a particular test are outlined in Table 1. The most effect test for screening defects in flight hardware is the thermal-vacuum test (Ref. 2). Consequently, a thermal-vacuum test is the primary screen for anomalies in electronic devices during pre-launch testing. However, dynamics tests were identified as the potential screen for anomalies related to the launch phase or pyrotechnic events, and EMC tests were identified for anomalies that could be correlated to spacecraft internal events. Table 1 provides criteria for only thermal-vacuum tests, dynamics tests, and EMC tests. Occasionally the specific nature of the anomaly suggested some other test or suggested that no pre-launch environmental test was potentially effective as a screen. When this occurred, either the test suggested by the nature of the anomaly was identified or no test was indicated.

Table 1. Criteria for Assigning Anomaly to Ground Test

GROUND TEST ASSIGNMENT	CRITERIA
DYNAMICS	The anomaly occurred during or very near the launch phase of the mission or occurred during pyrotechnic events during launch vehicle staging, the deployment of various devices or structures, etc.
THERMAL/VACUUM	The anomaly occurred in electronic devices or was related to degradation of materials.
ELECTROMAGNETIC COMPATIBILITY	The anomaly can be correlated to other spacecraft events or is related to grounding or isolation defects.

The anomalies for the first 200 days after launch are characterized in Table A in the Appendix for the Mariner 71, Viking Orbiter, Voyager and Galileo. The anomalies for each of these pro ects were reviewed and by applying the above criteria a potential ground test was identified. For some anomalies no ground environmental test could be identified. Table

*200 days is long enough to approximately envelop the worst-case early time period defined in Reference 1. The early time period varied from about 10 days for Voyager to 208 days for Mariner 71.

A also contains the pro ect on which the anomaly occurred and the number of days after launch when it occurred. Table 2 provides a summary of the number of times a particular test was identified as a potential screen.

Table 2. Summary of Potential Tests to Detect In-Flight Anomalies

S/C	T/V	DYN	EMC	S/W	LIFE	CAL	RAD	N/T
MM		5	2		2			
VIK1				1	1	2		
VIK2		1		2		2		
VOY1			1					1
VOY2	1		1					2
GLL	5	1	2		1	1	1	4
TOTAL	6	7	6	3	4	5	1	7

Note: S/C - SPACECRAFT
T/V - THERMAL-VACUUM TEST
DYN - DYNAMICS TEST (POWER ON)
EMC - ELECTROMAGNETIC COMPATIBILITY
S/W - TEST OF SOFTWARE OR PROGRAMMING
LIFE - LIFE TEST (OR OPERATIONAL TEST FOR AN EXTENDED PERIOD)
N/T - NO TEST
MM - MARINER 71
VIK - VIKING
VOY - VOYAGER
GLL - GALILEO

The presentation of the data in Table 2 supports several extremely important points:

1. Environmental testing on the Voyager pro ect was very effective and provides a model for the approach to environmental testing on other flight pro ect.

   The Voyager 1 spacecraft experienced only 2 significant anomalies during the first 200 days after launch. One anomaly (a false pyro indication resulting from unbalanced grounding) occurred on the first day after launch. An EMC test possibly could have detected this problem. The other anomaly occurred on the ninth day after launch. No ground test could be identified to detect this anomaly prior to launch.

   Only 4 significant anomalies occurred on Voyager 2 during the first 200 days. One anomaly was similar to the Voyager 1 pyro indication anomaly. A second anomaly (no indication of a successful squib firing) also occurred on the first day after launch.

This defect might have been detected by a dynamics or a thermal-vacuum test. The other two anomalies occurred on the eleventh and twenty-fifth days after launch and could not have been detected by a pre-launch environmental test.

The relatively small number of flight anomalies occurred because of the quality of the flight hardware and the extensiveness of the Voyager test program. A complete set of assembly-level qualification hardware and a proof-test model (PTM) spacecraft were available for environmental testing. This quantity and quality of flight hardware has not been available since that time.

The performance of the two Voyager spacecraft clearly supports the conclusion that a Voyager Program approach leads to long-life spacecraft with few in-flight anomalies.

2. For early spacecraft (such as Mariner 71), performing vibration tests with the flight hardware powered-on potentially would have screened out five of the nine indicated anomalies. EMC testing would have screened out half of the remaining four anomalies. The apparent potential effectiveness of dynamics testing as an additional screen does not appear in the later pro ects.

3. The Galileo spacecraft experienced in-flight anomalies that would require a variety of environmental tests to screen. This fact is probably related to the nature of the pro ect. Considerable redesign of the spacecraft occurred after the Challenger accident. In addition, the requirement to use the STS as a launch vehicle caused considerable stretchout in the pro ect schedule and placed constraints on the upper stage propulsion system employed. The spacecraft system was redesigned to accommodate a solid upper stage in place of the original liquid upper stage. The pro ect performed considerable testing prior to the redesign and again after the redesign. Perhaps, the pro ect should have performed even more retesting.

4. EMC testing appears to have gone through a stage where additional screening would have been effective on Mariner 71, to a stage where no additional testing is indicated on Viking, to a stage where the need for additional EMC testing appears to be increasing. The conclusion reached in reference 3 supports this observation.

Table 2 indicates that a radiation test might have effectively screened the anomaly on Galileo related to radiation induced spikes in the imaging subsystem. Radiation testing is a significant aid in assessing radiation induced rate effects as well as radiation damage to flight hardware. A well-designed radiation test can expose electronic parts and hardware designs that are susceptible to radiation effects. However, radiation tests are not performed on flight hardware because the radiation test may induce permanent damage in the hardware. Radiation testing is a good example of testing that can be performed on non-flight hardware and the results used to qualify the flight hardware by similarity.

The totals in Table 2 indicate 19 out of 39 of the anomalies could potentially have been screened out by appropriately performing a thermal-vacuum test, a powered-on vibration test and an EMC test. Other types of testing could have eliminated another 13 out of the remaining 20 in-flight anomalies. Consequently, adequate ground testing can reduce in-flight anomalies. The Voyager test program provides the general guidelines for a superior environmental test program.

Guidelines in specific detail for a cost-effective test program, especially as the guidelines apply to the new generation high-technology hardware, should be defined. The Voyager test program provides a starting point for establishing these guidelines. However, the guidelines need to be further refined in the era of faster, better, cheaper spacecraft design.

APPENDIX

OBSERVED SPACECRAFT ANOMALIES AND POTENTIAL TESTS

This appendix documents the review of in-flight anomalies which occurred on the Mariner 71, Viking, Voyager, and Galileo spacecraft. The review only includes anomalies occurring during the first 200 days for each spacecraft mission. The first 200 days was chosen to approximately envelop the upper limit for the "**early flight period"** defined in Reference 1. This period corresponded to the period where it was inferred that additional testing might reduce the initial flight anomaly rate. If this inference is correct, then pre-launch ground tests could lead to the identification of hardware workmanship or design defects which caused the anomaly.

Table A summarizes the results for each spacecraft. The table identifies the spacecraft, indicates the time from launch when the anomaly occurred, summarizes the nature of the anomaly and indicates a potential test that might have identified the anomaly during ground testing. For some test, the tests as they are currently performed may have to be modified in some way, such as by increasing the instrumentation sensitivity and reducing background noise. Given these caveats, pre-launch ground tests exist which identify defects which caused the in-flight anomalies. This result generally supports the conclusion drawn in Reference 1.

A few anomalies were related to calibration type problems. Included in this class were alignment errors, possible error in determination of the spacecraft mass and center of mass. Other anomalies were related to a variety of causes not typically found during thermal-vacuum tests, dynamics tests or EMC tests. For some of these anomalies, the nature of the anomaly suggested a possible method for screening the underlying defect. However, a potential pre-launch ground test was not identified for several of the anomalies. These are labeled as unknown or no pre-launch test in the potential test column. However, considering the sum of these, the total number is small enough that they have very little impact on the result.

Table A. Spacecraft Anomaly and Potential Screen Test

SPACECRAFT	TIME AFTER LAUNCH (DAYS)	ANOMALY	POTENTIAL TEST
Mariner 71	1	DSS-71 sync problems caused by R.F. leakage.	EMC
Mariner 71	4	Exciter output dropped more than expected due to zenering in X30 frequency multiplier.	POWER-ON DYNAMICS TESTS
Mariner 71	19	Excess limit-cycle velocity caused gas loss due to resistors in 12V supply causing unregulated sun sensor voltage.	POWER-ON DYNAMICS TESTS
Mariner 71	40	Random telemetry-channel null outputs due to possible intermittent short.	POWER-ON DYNAMICS
Mariner 71	84	High-frequency exciter degradation in X30 exciter module.	POWER-ON DYNAMICS
Mariner 71	115	Roll-axis gas valve leakage due to non-metallic particle on gas seat.	LIFE TEST
Mariner 71	148	Roll valve leaking.	LIFE TEST
Mariner 71	172	FCS voltage control oscillator rest frequency change due to low RFS gain.	
Mariner 71	192	TWTA failure, possibly due to movement of TWT cathode.	POWER-ON DYNAMICS
Viking 1	49	Wrong response from IRTM when it was turned on.	SOFTWARE
Viking 1	52	Low response from MAWD instrument	CALIBRATE
Viking 1	52	MAWD instrument response loss due to internal calibration measurement.	CALIBRATE
Viking 1	151	Pressure regulator failed due to propellant deposit on seat.	LIFE
Viking 2	2	Error in processor probably due to launch transient	POWER-ON DYNAMICS
Viking 2	38	Wrong response from IRTM when it was turned on.	SOFTWARE
Viking 2	38	Low response from MAWD instrument	CALIBRATE

Table A. Spacecraft Anomaly and Potential Screen Test (Continued)

SPACECRAFT	TIME AFTER LAUNCH (DAYS)	ANOMALY	POTENTIAL TEST
Viking 2	39	Wrong response from IRTM when it was turned on.	SOFTWARE
Viking 2	59	Telescope could not fully view diffuser plate.	ALIGNMENT
Voyager 1	1	False pyro amp indication due to unbalanced grounding design.	EMC
Voyager 1	9	Plume impingement caused a 20% lower delta V	REVIEW
Voyager 2	1	False pyro amp indication due to unbalanced grounding design.	EMC
Voyager 2	1	No indication received of a successful squib-firing-current output. Cause of failure not certain. Possible electronic part failure.	DYNAMICS/ THERMAL-VACUUM
Voyager 2	11	Plume impingement caused a 20% lower delta V.	REVIEW
Voyager 2	25	Excessive attitude control gas usage during one sequence.	NO PRE-LAUNCH TEST
Galileo	1	Interference observed in plasma wave experiment magnetic search coil sensor from UV spectrometer	EMC
Galileo	1	RFS receiver local oscillator drive dropped.	POWER-ON DYNAMICS
Galileo	3	AC/DC bus imbalance caused by slip-ring debris in spin bearing assembly causing shorts.	LIFE
Galileo	5	One of a series of RTG temperature transducer problems.	THERMAL-VACUUM
Galileo	21	Inertial turn had larger turn than expected.	MASS/CG
Galileo	23	Radiation induced spikes in solid state imaging subsystem.	RADIATION

Table A. Spacecraft Anomaly and Potential Screen Test (Continued)

SPACECRAFT	TIME AFTER LAUNCH (DAYS)	ANOMALY	POTENTIAL TEST
Galileo	24	Failed retro-propulsion module (RPM) temperature transducer caused alarm, open-circuit between transducer and CDS. Tra ectory correction maneuver (TCMs) performed without problem.	THERMAL-VACUUM
Galileo	79	Image processing lab unable to Reed-Solomon decode.	UNKNOWN
Galileo	83	NIMS focal plane array temperature dropped slower than expected due to failure of cover to deploy caused by thermal distortion resulting from turn-on of heater prior to cover deployment	COMMAND PROCEDURE
Galileo	90	SBA rate became noisy after SEQID (software command) disable in cruise mode.	COMMAND PROCEDURE
Galileo	97	One of series of RTG temperature transducer problems.	THERMAL-VACUUM
Galileo	109	Scan actuator violation counts.	UNKNOWN
Galileo	146	One of series of RTG temperature transducer problems.	THERMAL-VACUUM
Galileo	174	Failed temperature transducer caused alarm, open circuit between transducer and CDS. TCMs performed without problem	THERMAL-VACUUM
Galileo	196	CRC PORs recorded by way of telemetry indications. Probable cause as the AC/DC bus imbalance.	EMC